

CLAIMS

What is claimed is:

1. A method of reactivating a catalyst, comprising:
providing a catalyst that is at least partially deactivated by one or more fouling agents, the catalyst comprising a solid catalyst or a liquid catalyst;
contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities;
reacting the fluid reactivating agent with at least one fouling agent;
releasing the at least one fouling agent from the catalyst;
removing the at least one fouling agent from the fluid reactivating agent; and
recycling the fluid reactivating agent.
2. The method of claim 1, wherein providing a catalyst that is at least partially deactivated by one or more fouling agents comprises providing the catalyst that catalyzes an alkylation reaction, a transesterification reaction, an esterification reaction, an oligomerization reaction, a polymerization reaction, or an isomerization reaction.
3. The method of claim 1, wherein providing a catalyst that is at least partially deactivated by one or more fouling agents comprises providing the catalyst that includes an acid functionality or a base functionality
4. The method of claim 1, wherein providing a catalyst that is at least partially deactivated by one or more fouling agents comprises providing the catalyst that is at least partially deactivated by hydrogen deficient fouling agents.
5. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent comprising a solvent that reacts with the at least one fouling agent in a way that facilitates their removal, in total or in part, from a surface of the catalyst.

6. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent that is capable of transferring a hydride ion to the at least one fouling agent.

7. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent comprising an alkane having at least one tertiary carbon atom or a compound that can be isomerized in the presence of the catalyst to form at least one tertiary carbon atom.

8. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent comprising a compound selected from the group consisting of isobutane, isopentane, and mixtures thereof.

9. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent comprising a compound selected from the group consisting of n-butane, n-pentane, and mixtures thereof.

10. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent comprising an aromatic compound selected from the group consisting of benzene, toluene, ethylbenzene, and mixtures thereof.

11. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to

dissolve impurities comprises contacting the catalyst with the fluid reactivating agent comprising at least one of a dissolved species of hydrogen or oxygen.

12. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent at pressure and temperature conditions such that the fluid reactivating agent is a critical fluid.

13. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent at a pressure equal to a critical pressure ("P_c") and at a temperature equal to a critical temperature ("T_c").

14. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent at pressure and temperature conditions such that the fluid reactivating agent is a supercritical fluid.

15. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent at a pressure greater than P_c and at a temperature greater than T_c.

16. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with the fluid reactivating agent at a pressure in the range of about 0.1 P_c to about 8 P_c, and a temperature in the range of about 0.9 T_c to about 1.3 T_c.

17. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to

dissolve impurities comprises contacting the catalyst with isobutane at a temperature in the range of about 100°C to about 300°C.

18. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with isobutane at a pressure in the range of about 200 psig to about 5000 psig.

19. The method of claim 1, wherein contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises contacting the catalyst with a fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve at least one of the fouling agents and products of a reaction of the fluid reactivating agent with the fouling agents

20. The method of claim 1, wherein reacting the fluid reactivating agent with the at least one fouling agent comprises stabilizing the at least one fouling agent.

21. The method of claim 1, wherein reacting the fluid reactivating agent with the at least one fouling agent comprises transferring a hydride ion from the fluid reactivating agent to the at least one fouling agent.

22. The method of claim 1, wherein releasing the at least one fouling agent from the catalyst comprises releasing the at least one fouling agent having a molecular weight approximately equal to or higher than the molecular weight of the at least one fouling agent deposited on the solid catalyst.

23. The method of claim 1, wherein releasing the at least one fouling agent from the solid catalyst comprises desorbing the at least one fouling agent from the solid catalyst and dissolving the at least one fouling agent in the fluid reactivating agent.

24. The method of claim 1, wherein removing the at least one fouling agent from the fluid reactivating agent comprises adsorbing the at least one fouling agent to a solid material.

25. The method of claim 24, wherein adsorbing the at least one fouling agent to a solid material comprises adsorbing the at least one fouling agent to a solid material selected from the group consisting of alumina, molecular sieves, and activated carbon.

26. The method of claim 1, wherein removing the at least one fouling agent from the fluid reactivating agent comprises removing the at least one fouling agent from the fluid reactivating agent in a supercritical phase, a liquid phase, or a gas phase.

27. The method of claim 1, wherein removing the at least one fouling agent from the fluid reactivating agent comprises precipitating the at least one fouling agent from the fluid reactivating agent.

28. The method of claim 27, wherein precipitating the at least one fouling agent comprises altering solubility properties of the fluid reactivating agent.

29. The method of claim 1, wherein removing the at least one fouling agent from the fluid reactivating agent comprises using the at least one fouling agent with a recycling catalyst.

30. The method of claim 1, wherein recycling the fluid reactivating agent comprises reusing the fluid reactivating agent as at least a portion of the feed mix or as a reactivating agent.

31. The method of claim 1, wherein recycling the fluid reactivating agent comprises using a first portion of the fluid reactivating agent as at least a portion of a feed mix and a second portion of the fluid reactivating agent as a reactivating agent.

32. A system for reactivating a catalyst, comprising:
at least one reactor for holding at least one catalyst that is at least partially deactivated by fouling agents;

a first pumping device to direct a fluid reactivating agent toward the catalyst, wherein the fluid reactivating agent is capable of reacting with impurities, the impurities comprising at least one fouling agent and products of a reaction of the fluid reactivating agent with the at least one fouling agent;

pressure and temperature control devices for generating pressure and temperature conditions while the catalyst is in contact with the fluid reactivating agent such that the fluid reactivating agent is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve the impurities;

a second pumping device configured and operably coupled to direct contaminated fluid reactivating agent to a reactivating agent recovery, the contaminated fluid reactivating agent including the fluid reactivating agent and the at least one fouling agent; and

a third pumping device configured and operably coupled to recirculate clean fluid reactivating agent from the reactivating agent recovery to the at least one reactor.

33. The system of claim 32, wherein the catalyst comprises a solid catalyst or a liquid catalyst.

34. The system of claim 32, wherein the at least one reactor comprises at least a first reactor and a second reactor, the first and second reactors configured in a swing column apparatus that permits controlled and independent direction of the flow of reactants and the flow of the fluid reactivating agent.

35. The system of claim 32, wherein the first and second reactors are continuous stirred tank reactors such that the first reactor provides a reactivation zone for regeneration of the catalyst and the second reactor provides a reaction zone for an alkylation reaction, a transesterification reaction, an esterification reaction, an oligomerization reaction, a polymerization reaction, or an isomerization reaction.

36. The system of claim 32, wherein the pressure and temperature control devices are configured to adjust the pressure and temperature conditions such that the fluid reactivating agent is a near-critical liquid, or in a critical or a supercritical phase.

37. The system of claim 32, wherein the pressure and temperature control devices are configured to adjust the pressure and temperature conditions such that the fluid reactivating agent is a near-critical gas, or in the critical or supercritical phase.

38. A method of reactivating a catalyst, comprising:
directing a fluid reactivating agent towards at least one catalyst that is at least partially deactivated by fouling agents, the at least one catalyst located in at least one reactor;

contacting the at least one catalyst with the fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities;

reacting the fluid reactivating agent with at least one fouling agent;

forming a contaminated fluid reactivating agent comprising the at least one fouling agent;

directing the contaminated fluid reactivating agent to a reactivating agent recovery;

removing the at least one fouling agent from the fluid reactivating agent; and

recycling the fluid reactivating agent.

39. The method of claim 38, wherein directing a fluid reactivating agent towards at least one catalyst that is at least partially deactivated by fouling agents comprises directing the fluid reactivating agent towards at least one liquid catalyst or at least one solid catalyst.

40. The method of claim 38, wherein directing a fluid reactivating agent towards at least one catalyst that is at least partially deactivated by fouling agents comprises directing the fluid reactivating agent using a first pumping device.

41. The method of claim 38, wherein directing the contaminated fluid reactivating agent to a reactivating agent recovery comprises directing the contaminated fluid reactivating agent using a second pumping device configured and operably coupled to direct the contaminated fluid reactivating agent to the reactivating agent recovery.

42. The method of claim 38, wherein recycling the fluid reactivating agent comprises recycling the fluid reactivating agent using a third pumping device configured and operably coupled

to recirculate clean fluid reactivating agent from the reactivating agent recovery to the at least one reactor.

43. The method of claim 38, wherein contacting the at least one catalyst with the fluid reactivating agent that is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve impurities comprises generating pressure and temperature conditions such that the fluid reactivating agent is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve the impurities.

44. The method of claim 43, wherein generating pressure and temperature conditions such that the fluid reactivating agent is at or above a critical point of the fluid reactivating agent and is of sufficient density to dissolve the impurities comprises using at least one of a pressure control device and a temperature control device to generate the pressure and temperature conditions.